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PACER LIME: Part II - Experimental Determination of Environmental Corrosion Severity

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Atmospheric exposure of aircraft alloys was conducted to provide experimental data in support of an environmental rating system. Alloys tested were magnesium AZ31B, 4340 steel, aluminum 2024-T3 Alclad, 7075-T6, 7079-T6 Alclad, and titanium-6Al-4V. Test sites were nine in the continental U.S., one in Hawaii, and one in England. Measured corrosion rates are in good agreement with literature values and USAF corrosion maintenance experience.

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PREFACE

This is the Final Report for USAF Aeronautical System Divison Contract No. F33615-78-C-5224 with Michigan State University. The Program described was initiated by personnel of Warner-Robins Air Logistics Center Corrosion Management Office (WR-ALC/MMETC). It's objective is to develop an environmental corrosion severity classification system and to calibrate this system by means of an atmospheric testing program. After several years of development and testing by WR-ALC, analysis of the results was completed by MSU. The Final Report is divided into two parts which are issued separately. The first part discusses the environmental classification system, and this, the second part, treats the experimental phase.

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1. INTRODUCTION

In response to the needs of the Strategic Air Command (SAC), the AF Logistics Command (AFLC) implemented a program to develop a corrosion severity classification for each operational airbase as part of the Corrosion Prevention and Control (COPCON) program (redesignated as Project RIVET BRIGHT in 1971). Program development began in 1965 and implementation was achieved in 1971. The program was designated PACER LIME in 1972 as an element of RIVET BRIGHT. PACER LIME is a two phase effort: (1) Development of an equation or algorithm for computing a priori a numerical corrosion factor which combines weather and other environmental factors; (2) experimental measurement of corrosion severity at selected locations through atmospheric corrosion tests. The experimental data would be used to "calibrate" the computed corrosion factor.

An initial corrosion factor equation, combining certain weather and geographical factors, was developed in 1971. Interim numerical classifications were published for 39 SAC airbases in 1972, and for 95 USAF and 27 ANG airbases in 1973. A complete list was distributed in 1974 under the title "PACER LIME Interim Corrosion Severity Classification." These interim values were to be compared with corrosion maintenance experience and the results of the PACER LIME atmospheric testing program. The corrosion factor equation then would be modified and used to compute working corrosion severity classifications. The experimental phase produced useful data very slowly, however, and analysis of maintenance experience proved to be more complex than expected. Consequently, revision of the corrosion factor equation has been delayed considerably.

2. PACER LIME--Atmospheric Corrosion Testing

2.1 OBJECTIVE

The experimental phase of PACER LIME was intended to provide a calibration for the corrosion severity index (CSI) algorithm. Corrosion of selected alloys would be used to compare environmental corrosivity at several airbases selected to span the range of actual environments. Comparative evaluation of the alloys tested was not a consideration. The alloys would be representative of those used in airframe construction.

2.2 THE TESTING PROGRAM

2.2.1 TESTING SITES

Warner-Robins Air Logistics Center completed detailed planning of this phase in 1971. Eleven test sites were planned, including seven CONUS, two USAFE, and two PACAF airbases. Because of cost considerations, however, the number of overseas test sites was reduced to two. Test locations, together with relevant data, are listed in Table 1. These sites were selected partly on the basis of the then-developing CSI algorithm, and were intended to represent as wide a range as possible of environmental severities. As it turned out, however, most of the locations were classed as "moderate," while two were "severe" and one "very mild." Unfortunately, no useful data were obtained from either of the "severe" locations.

Most exposure sites were located in a general airbase environment, i.e., a few hundred yards distance from operational runways or taxiways. Exceptional environmental factors at some bases include an aircraft wash rack at 200 yards (Barksdale), fuel depot at 100 yards (Norton), and fuel depot and sewage treatment plant at 300 yards (Robins). No details of stand location are available for Andrews, Hickam, MacDill, and F. E. Warren, all of whom reported poor data as well.

The experimental phase of PACER LIME would provide a calibration for the corrosion factor equation by measuring corrosion rates at several airbases. The test sites were selected to span the range of environments from mildest to most severe. Alloys representative of modern airframe construction were chosen for outdoor exposure. Program planning was completed in 1971, most test stands were installed in 1972, and the remaining stands were installed in 1973 and 1975. Despite numerous difficulties and misfortunes, considerable data was accumulated between 1972 and 1978. Analysis of the data, in terms of environmental parameters, however, proved to be more complex than expected.

In 1978 it was determined that adequate in-house USAF resources could not be made available for the completion of PACER LIME, and the Program was assigned under contract to Michigan State University. The objectives of the MSU effort were to complete the program by analyzing results of the corrosion exposure test program, the Base Corrosion Severity Classification System, and to develop an improved classification system. This improved system was to be applied to the environments of all USAF, AFRES, and ANG airbases in order to provide ratings for each. These objectives have been accomplished and are discussed in this Final Report.

The Report is divided into two parts, which are being published separately. The first part discusses the Corrosion Severity Classification System and the second part the Corrosion Exposure Test Program.

Table 1. PACER LIME Atmospheric Corrosion Testing Sites

	Date Installed	Interim CSI
1. Andrews, Washington D.C.[a]	3/72	2.50 MOD
2. Barksdale, Louisiana	3/72	2.83 MOD
3. Davis-Monthan, Arizona	3/72	3.33 MIL
4. Hickam, Hawaii[b]	9/73	2.50 MOD
5. MacDill, Florida[c]	3/72	1.83 SEV
6. Norton, California	3/72	2.50 MOD
7. Robins, Georgia[b]	9/73	2.83 MOD
8. Tinker, Oklahoma	3/72	2.83 MOD
9. Francis E. Warren, Wyoming	3/72	3.00 MIL
10. Wright-Patterson, Ohio[c]	3/72	2.67 MOD
11. RAF Lakenheath, England[bc]	8/75	1.83 SEV

[a]Initially Bolling AFB, Washington, D.C. was selected, but was found to have no corrosion specialist personnel.

[b]Original choices were PACAF locations Nakhon Patham Airport, Thailand, Kunsan AB, Korea and USAFE locations RAF Alconbury, England, and Torrejon AB, Spain. Test sites listed above were substituted primarily to minimize costs.

[c]Test racks were destroyed by weather; only at Wright-Patterson AFB was facility reestablished.

2.2.2 TEST METHODS AND MATERIALS

Test stands, similar to ASTM specification G 50-76,[1] were constructed to hold about 125 test panels by means of porcelain insulators at 30° to the horizontal facing prevailing winds. Test stand installation was accomplished at eight sites in March 1972, two more in September 1973, and the last one in late summer 1975.

Six alloys* were selected and tested in three different configurations (Table 2). The riveted assembly of three aluminum alloys was intended to provide galvanic corrosion. Thus the corrosion damage to these panels should represent fairly the behavior of aircraft in a given environment. The corrosion of steel and magnesium was thought to be predictable and fast enough to give results in a reasonable time. Since aluminum usually does not exhibit extensive general corrosion, it was anticipated that sporadic, difficult to interpret results might be obtained. The corrosion behavior of titanium was considered predictable, but it also was known to be exceedingly slow.

Procedures for initial test stand setup and specimen handling were formulated to correspond closely with ASTM G 1-72 and G 50-76.[1] An analytical balance with 300 ± .001 g capacity was specified, but test panels could be trimmed slightly if a smaller capacity balance was available. Panels were identified by stamped code and installed on the test racks according to a specified sequence by alloy and panel number. Prior to initial exposure, test panels were solvent degreased (using "Benzene, methyl ethyl ketone, toulene, etc."), and descaled ("remove contamination") mechanically (by means of "glass bead blast, 400 grit paper, aluminum wool, stainless steel

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*From hindsight, it is unfortunate that a low carbon steel and perhaps zinc were not included, since these metals are so common in published corrosion tests.

Table 2. Materials Tested in PACER LIME Program

Code	Number of Panels	Size	Materials
01	12 ea	12.7 x 14.3 cm	2024 T3 (clad)
03	12 ea	12.7 x 14.3 cm	7075 T6
05	12 ea	12.7 x 14.3 cm	7079 T6 (clad)
07	12 ea	12.7 x 14.3 cm	4340
09	12 assemblies	12.7 x 14.3 cm	*
11	12 ea	12.7 x 14.3 cm	Mg AZ31B-0
13	12 ea	12.7 x 14.3 cm	Ti 6Al 4V
15	5 ea	12.7 x 29.8 cm	2024 T3 (clad)
17	5 ea	12.7 x 29.8 cm	7075 T6
21	5 ea	12.7 x 29.8 cm	Mg AZ31B-0

99 Total panels for each test stand.

*The assemblies were made from one panel each of

(clad) 2024 T3
7075 T6
(clad) 7079 T6

each panel was 12.7 x 6.4 cm. The assemblies were riveted with 4 cadmium plated rivets and assembled as shown in Figure 1.

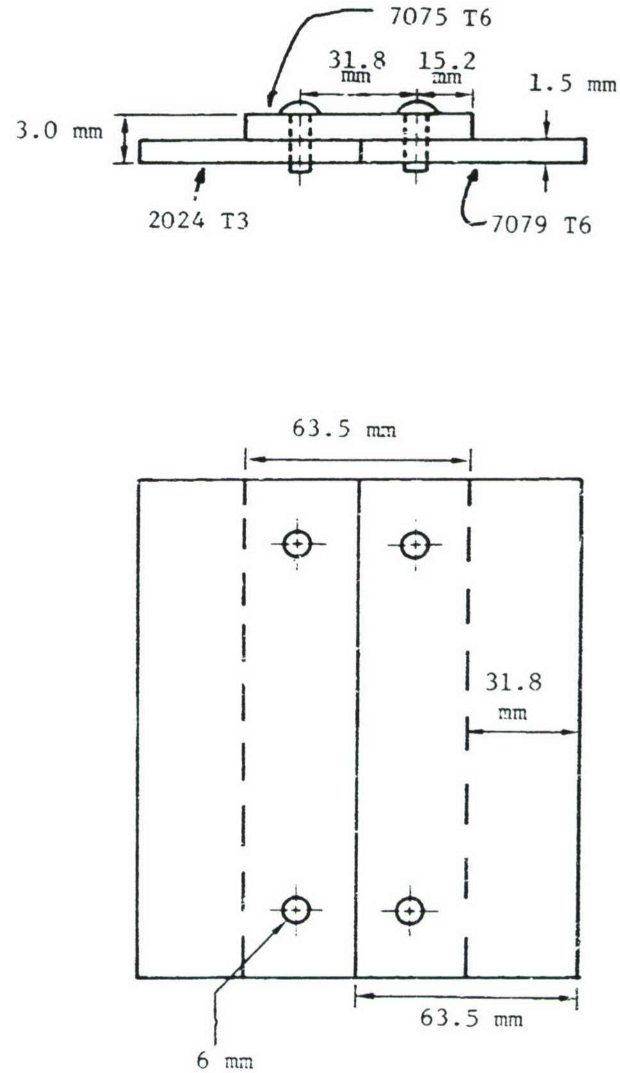

Figure 1. Aluminum assembly configuration.

wool, etc."). Following a rinse in MEK, they were to be weighed to the nearest milligram, then handled only with rubber gloves and wrapped in soft paper.

At six month intervals, all panels were removed, scrubbed with a rubber stopper under flowing water, acetone-rinsed, dried, and weighed.

2.3 PROBLEMS

The initial setup procedure was too flexible, but since all test stands were set up by personnel from Warner-Robins ALC, this does not seem to have been a source of difficulty. There is evidence (e.g., weights recorded to the nearest 0.0001g) that reasonable care was taken at this and every subsequent step of the program.

The decision to remove, clean, and weigh every panel at six month intervals was unfortunate, although the reasons seemed compelling at the time (viz., loss of initial data) and such measurements could show variation in the corrosion rate with seasonal and pollutant changes. On the other hand, data are lost which relate to the long term effects of corrosion products on reaction rate. Moreover, the task of multiple weighings results in a greater chance of error on the part of laboratory personnel as well as a reluctance to do the work.

The cleaning procedure prior to weighing was selected to avoid the hazards of chemical cleaning methods. Chemical methods remove corrosion products more effectively than the stopper-rubbing technique, hence yield more accurate weight loss measurements. Since many actual weight changes were quire small, the resultant errors probably are significant.

In addition to these problems, the program was plagued with numerous

difficulties from the outset. At most locations, either the required equipment (balance) or personnel were lacking, hence panel weighings could not be done locally. Only Robins, Tinker, Wright-Patterson, and Lakenheath possessed the needed capability. Specimens from other sites were removed, packaged, and shipped to Robins (from Andrews, Hickam, and Norton) or to Tinker (from Barksdale, Davis-Monthan, and F.E. Warren) for measurements.

It was discovered in 1976 that the balance in use at Tinker was out of calibration.[2] Presumably, the deviation resulted from a move of the equipment, which could be dated approximately as January 1975.

It was found in 1974 that all data from MacDill had been lost* because of personnel changes. A new set of panels was installed, but the test stand soon was destroyed by weather* and testing was discontinued. Virtually no data are available from MacDill. The late-installed stand at Lakenheath was destroyed by weather and testing was discontinued after only six months exposure; again, almost no data exist from Lakenheath. A similar misfortune occurred at Wright-Patterson, but the stand was replaced. This was especially unfortunate because both Lakenheath and MacDill were believed to be severe environments.

Steel panels were found to corrode so rapidly that the surface-marked identifications were obliterated; a new marking method was developed. Finally, when an attempt was made in 1975 to analyze the data, it was discovered that no initial weights had been recorded for most panel sets.

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*Not uncommon occurrences even in programs operated by the most experienced workers, cf. references 3, 4, 5.

3. RESULTS

3.1 DATA REDUCTION

Raw data sheets (most handwritten) were tabulated, keypunched and entered into a CDC 6500 Computer.

Mass change per unit area vs. time calculations were prepared for all alloys from all PACER LIME test sites from which data were available. A number of anomalous values were noted and checks were made to determine whether they had resulted from tabulation or keypunch errors, and appropriate corrections were made. To correct for other irregularities which were still obvious a subroutine was developed to calculate the mean mass change and to reject any data point which was more than three standard deviations away from the mean in either direction.

In addition to plotting mass change for each individual panel of each alloy, a curve-fitting algorithm was developed to produce plots of mass change for all panels of each alloy at each base. Plots were generated using a software system developed by the Department of Entomology at MSU called the Statistical Plotting On-line Command System (SPOCS). SPOCS was used both to analyze statistically and to plot sets of two-dimensional data. Slopes (corrosion rates) were calculated using an International Mathematical and Statistical Libraries Multiple Linear Regression Analysis subroutine (RLMUL).

3.2 CORROSION RATES

Computed corrosion rates are listed by location and alloy in Table 3. These values represent only those cases where data were sufficient to compute rates. Positive values, which indicate an apparent weight gain, obviously are in error and are rejected. In several cases, plotted data showed the

computed values to be faulty or based on insufficient data points and these too have been rejected. In a few cases, hand computed values have been substituted. All rejected values are enclosed in parentheses.

It should be emphasized that the remaining values were not rejected simply because there was no obvious reason for doing so. There must always be some doubt about apparently valid data surrounded by obviously erroneous results.

Table 3. Corrosion Rates

LOCATION	ALLOY - PANEL SIZE			CORROSION RATE (KG/M**2-DAY)	
ANDREWS	2024 T3	ALUMINUM	.127X.143	(-1.73E-07)	
	7075 T6	ALUMINUM	.127X.143	-2.84E-06	
	7079 T6	ALUMINUM	.127X.143	-3.56E-06	
	4340	STEEL	.127X.143	(6.13E-05)	
	ASSEMBLY	ALUMINUM	.127X.143	-2.44E-06	
	AZ31B	MAGNESIUM	.127X.143	(-3.61E-05)	
	TI-6AL-4V	TITANIUM	.127X.143	(-4.26E-06)	
	2024 T3	ALUMINUM	.127X.299	(2.41E-07)	
	7075 T6	ALUMINUM	.127X.299	-6.75E-07	
	AZ31B	MAGNESIUM	.127X.299	-2.68E-05	
BARKSDALE	2024 T3	ALUMINUM	.127X.143	-1.05E-06	
	7075 T6	ALUMINUM	.127X.143	-1.36E-06	
	7079 T6	ALUMINUM	.127X.143	(1.35E-07)	
	4340	STEEL	.127X.143	-1.00E-04	
	ASSEMBLY	ALUMINUM	.127X.143	-2.12E-06	
	AZ31B	MAGNESIUM	.127X.143	-2.38E-05	
	TI-6AL-4V	TITANIUM	.127X.143	(2.52E-06)	
	2024 T3	ALUMINUM	.127X.299	(-8.96E-08)	
	7075 T6	ALUMINUM	.127X.299	(-2.56E-06)	
	AZ31B	MAGNESIUM	.127X.299	-7.02E-05	
BAV-MONT	7075 T6	ALUMINUM	.127X.143	(-2.34E-05)	
	7079 T6	ALUMINUM	.127X.143	(2.96E-07)	
	4340	STEEL	.127X.143	(-4.06E-04)	1.6 E-03
	ASSEMBLY	ALUMINUM	.127X.143	(1.64E-06)	
	AZ31B	MAGNESIUM	.127X.143	-1.82E-05	
	TI-6AL-4V	TITANIUM	.127X.143	(3.88E-07)	
	2024 T3	ALUMINUM	.127X.299	(4.63E-06)	
	7075 T6	ALUMINUM	.127X.299	-4.17E-06	
	AZ31B	MAGNESIUM	.127X.299	(4.32E-06)	

LOCATION	ALLOY - PANEL SIZE	CORROSION RATE (KG/M**2-DAY)
HICKAM	2024 T3 ALUMINUM .127X.143	(1.03E-05)
	7075 T6 ALUMINUM .127X.143	(1.50E-06)
	7079 T6 ALUMINUM .127X.143	(1.85E-06)
	AZ31B MAGNESIUM .127X.143	(2.08E-05)
	TI-6AL-4V TITANIUM .127X.143	(1.74E-06)
NORTON	2024 T3 ALUMINUM .127X.143	(3.80E-06)
	7075 T6 ALUMINUM .127X.143	(5.61E-06)
	7079 T6 ALUMINUM .127X.143	(6.47E-06)
	4340 STEEL .127X.143	(5.10E-05)
	ASSEMBLY ALUMINUM .127X.143	(8.36E-06)
	AZ31B MAGNESIUM .127X.143	(-6.72E-06)
	TI-6AL-4V TITANIUM .127X.143	(1.55E-06)
	2024 T3 ALUMINUM .127X.299	(9.47E-06)
	7075 T6 ALUMINUM .127X.299	(8.98E-06)
	AZ31B MAGNESIUM .127X.299	(2.34E-05)
ROBINS	2024 T3 ALUMINUM .127X.143	(-1.91E-07)
	7075 T6 ALUMINUM .127X.143	(-2.28E-07)
	7079 T6 ALUMINUM .127X.143	-2.76E-07
	4340 STEEL .127X.143	-1.25E-04
	ASSEMBLY ALUMINUM .127X.143	-2.07E-06
	AZ31B MAGNESIUM .127X.143	-3.57E-05
	TI-6AL-4V TITANIUM .127X.143	(8.14E-08)
	2024 T3 ALUMINUM .127X.299	-1.78E-07
	7075 T6 ALUMINUM .127X.299	(-2.09E-07)
	AZ31B MAGNESIUM .127X.299	-2.49E-05

LOCATION	ALLOY - PANEL SIZE			CORROSION RATE (KG/M**2-DAY)	
TINKER	2024 T3	ALUMINUM	.127X.143	-4.55E-07	
	7075 T6	ALUMINUM	.127X.143	-5.62E-07	
	7079 T6	ALUMINUM	.127X.143	-4.65E-07	
	4340	STEEL	.127X.143	-1.13E-06	
	ASSEMBLY	ALUMINUM	.127X.143	(6.54E-07)	
	AZ31B	MAGNESIUM	.127X.143	-2.70E-05	
	TI-6AL-4V	TITANIUM	.127X.143	(-2.91E-08)	
	2024 T3	ALUMINUM	.127X.299	-2.70E-07	
	7075 T6	ALUMINUM	.127X.299	-3.26E-07	
	AZ31B	MAGNESIUM	.127X.299	-2.24E-05	
WARREN	2024 T3	ALUMINUM	.127X.143	(-5.41E-08)	
	7075 T6	ALUMINUM	.127X.143	-3.96E-07	
	7079 T6	ALUMINUM	.127X.143	(-2.78E-07)	
	4340	STEEL	.127X.143	(6.26E-06)	
	ASSEMBLY	ALUMINUM	.127X.143	(3.54E-07)	
	AZ31B	MAGNESIUM	.127X.143	(-6.90E-06)	
	TI-6AL-4V	TITANIUM	.127X.143	(-2.95E-07)	
	2024 T3	ALUMINUM	.127X.299	(-2.41E-07)	
	7075 T6	ALUMINUM	.127X.299	-6.28E-07	
	AZ31B	MAGNESIUM	.127X.299	(4.49E-06)	-6.9E-06
WRIT-PATT	2024 T3	ALUMINUM	.127X.143	-5.16E-07	
	7075 T6	ALUMINUM	.127X.143	(1.84E-07)	
	7079 T6	ALUMINUM	.127X.143	(4.86E-06)	
	4340	STEEL	.127X.143	(7.09E-06)	-1.3E-04
	ASSEMBLY	ALUMINUM	.127X.143	(6.56E-08)	-4.61E-06
	AZ31B	MAGNESIUM	.127X.143	-5.10E-05	
	TI-6AL-4V	TITANIUM	.127X.143	(-1.02E-06)	
	2024 T3	ALUMINUM	.127X.299	(-1.44E-06)	
	7075 T6	ALUMINUM	.127X.299	(-1.62E-04)	
	AZ31B	MAGNESIUM	.127X.299	-3.13E-05	

4. DISCUSSION

Compared with the amount of data this study might have yielded, the presumably useful information actually obtained is disappointingly meager. Panels tested numbered 1089. As noted earlier, experimental weight-loss values for a given type panel were averaged for each test site, thus reducing the potential corrosion rate values to 110. Only 33 apparently valid corrosion rates, in fact, could be computed, for a rate of 30%. We also have pointed out the difficulty of taking such data seriously when they are surrounded by obviously-invalid data measured simultaneously by the same personnel. Nevertheless, we must accept the results at face value and compare them with measurements by other workers and with the environmental ratings of the corrosion severity algorithms.

4.1 OTHER RESULTS

Carter reported weight loss measurements on aluminum alloys exposed to industrial, rural, and marine environments. The alloys studied were identical to none in this study, but one contained copper and had a nominal composition similar to that of 2024. For that alloy, corrosion rates varied from 70×10^{-6} to 5×10^{-6} kg/m^2-day for severe industrial to rural environments, respectively. Marine and rural environments produce quite similar results and were relatively non-corrosive. Environmental pollutants--mainly SO_2--increased pitting attack, rather than general corrosion.

Pearlstein and Teitell (7) reported four year weight loss data for 2024 T3 and AZ31B exposed at three different sites in the Panama Canal Zone. Their results are reproduced in Table 4. Highest corrosion rates for both alloys were observed at the marine site and lowest in a rain forest. Weight losses in 2024 T3 were negligible in the latter environment. These authors commented,

however, that weight loss measurement may not be meaningful because 2024 exhibited extensive blistering and exfoliation corrosion without substantial weight loss. Pearlstein and Teitell's results for both alloys are approximately one order of magnitude larger than our measured corrosion rates for the most corrosive environment.

McGeary _et al_ (3) reported seven year weight loss data for several aluminum alloy exposed at four sites. Their results are reproduced in Table 5. Lowest corrosion rates were observed at the rural site for all alloys. Except for 7075 T6, highest rates were found at the moderately severe industrial environment. For 7075 T6, the highest rate occurred at the 80-foot Kure Beach NC site. Corrosion rates at marine and industrial sites are quite similar, however, and the reported differences may not be significant. This result is in contrast with Carter's (6) findings for a copper-containing aluminum alloy.

Corrosion rates for aluminum alloys exposed at several test sites, have been reported, (8-12), and the results are reproduced in Tables 5, 6, and 7. The industrial environment again is seen to be the most severe, whereas marine environments are somewhat milder. Ailor's seven year values are in good agreement with those of McGeary _et al_. Ailor also notes that intergranular and exfoliation corrosion were more dominant in marine environments, whereas weight loss and pitting corrosion were prevalent at the industrial sites.

Table 4. Corrosion Rates For Four Year Exposure in the Panama Canal Zone (after Pearlstein and Teitell[7]).

	Marine	Openfield	Rain Forest
2024 T3	9.75×10^{-5}	8.9×10^{-6}	negligible
AZ31B-0	4.8×10^{-4}	2.2×10^{-4}	$1.3. \times 10^{-4}$
			kg/m^2-day

Table 5. Corrosion Rates for Seven-year Exposure at Several Test Sites (after McGeary *et al*[3])

	Kure Beach 80-foot (E. Coast Marine)	Newark NJ (moderately severe industrial)	Point Reyes CA (W. Coast marine-1900 ft)	State College PA (rural)
2024 T3 Alclad	1.62×10^{-6}	2.04×10^{-6}	0.76×10^{-6}	0.34×10^{-6}
2024 T3 bare	3.77×10^{-6}	4.28×10^{-6}	2.97×10^{-6}	0.52×10^{-6}
7075 T6	5.67×10^{-6}	4.90×10^{-6}	4.61×10^{-6}	0.66×10^{-6}
7079 T6 Alclad	1.98×10^{-6}	2.96×10^{-6}	(lost)	0.43×10^{-6}
			kg/m^2-day	

Table 6. Corrosion Rates for Seven-year Exposure of 2024 T3 Aluminum at Several Test Sites (after Ailor[8])

	Kure Beach NC 800-ft (E. Coast Marine)	Corpus Christi TX 150-ft (Gulfcoast Marine)	Richmond VA (moderate industrial)	McCock IL (industrial)
1 year	7.62×10^{-6}	14.5×10^{-6}	23.6×10^{-6}	52.9×10^{-6}
2 years	1.89	5.92	18.0	33.2
7 years	2.17	2.57	4.40	7.14
				kg/m^2-day

Table 7. Corrosion Rates for One-year, Two-year, and Seven-year Exposure of Aluminum and Magnesium Alloys (after Copson[9], Pettibone[10,11], and Coburn[12]).

	Kure Beach NC 80 ft lot	Newark NJ	Point Reyes CA	State College PA
	Corrosion rate x 10^6 kg/m^2-day			
2024 T3 Alclad				
1 year	2.40	2.77	1.73	0.60
2 years	1.74	2.25	1.43	0.52
7 years	1.62	2.04	0.76	0.34
7075 T6				
1 year	9.87	5.77	7.75	1.18
2 years	6.85	4.34	6.33	0.90
7 years	2.46	3.29	1.15	0.42
7079 T6 Alclad				
1 year	1.28	2.63	0.99	0.60
2 years	2.26	2.68	2.28	0.60
7 years	*	4.85	*	0.49
AZ31B-H24				
2 years	86.7	134	71.1	90.3
7 years	71.6	129	55.5	68.1

* data considered unreliable

4.2 CORROSION RATES COMPARED WITH ENVIRONMENT

Sufficient data are available for environmental comparisons for AZ31B, 2024, and 7075 alloys only. In the case of 4043 and the aluminum assembly, there are only four data values each, hence they are insufficient. For 7079 there also are only four values, but there are several corrosion rates available from other studies to warrant comparison with the environment.

A semi-quantitative comparison with environment is made by plotting experimental corrosion rate versus the Corrosion Damage Algorithm rating for the respective test site. These are shown for the alloys AZ31B, 2024, 7075, and 7079 in Figures 2 through 5. Shown with the PACER LIME corrosion rates are the values obtained for the same alloys in other studies.

For the various sites, the CDA algorothm provides a two-letter scale, viz., BB, AB, etc. The first letter refers to the rating derived from a set of less-tolerant threshold values for environmental parameters, and the second from a more-tolerant set. Thus a second-letter A indicates a more severe environment, with respect to one or more environmental factor, than does a first letter A. Environmental ratings range from the mildest C through B and A to the most severe AA. For the purpose of data plotting, these letters have been assigned a numerical scale of 1 to 4 for C to AA, and the two-letter values summed. Thus an AB environment yields the sum 5, and AA, AA yields 8.

Data for the magnesium alloy, Figure 2, show a remarkably good correlation with the CDA rating, with only one or two discrepancies. The ASTM data for State College PA and Newark NJ both are unexpectedly high for their respective environmental ratings. The PACER LIME data, however, are quite consistent.

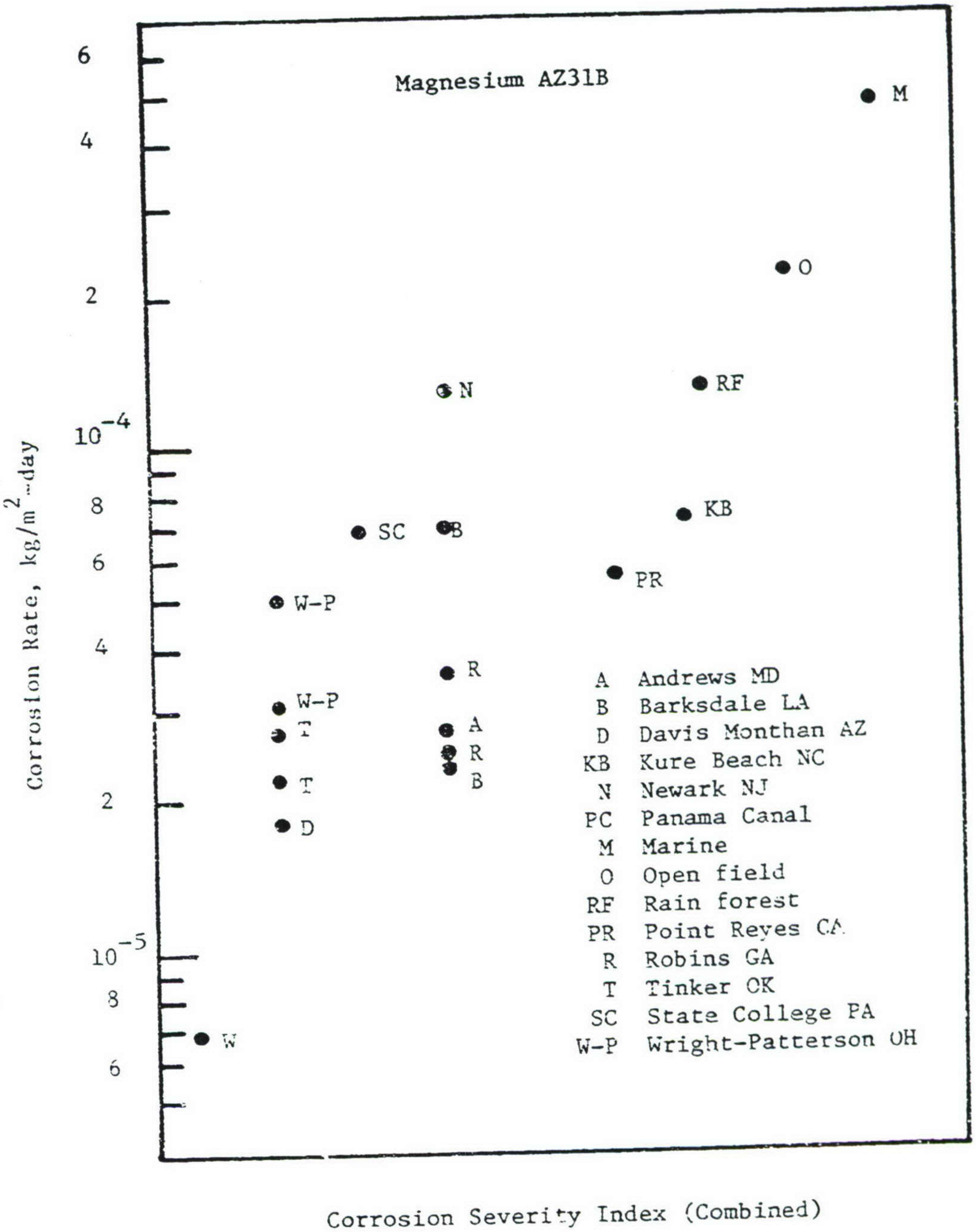

Figure 2. Corrosion rates of AZ31B magnesium alloy compared with environmental ratings.

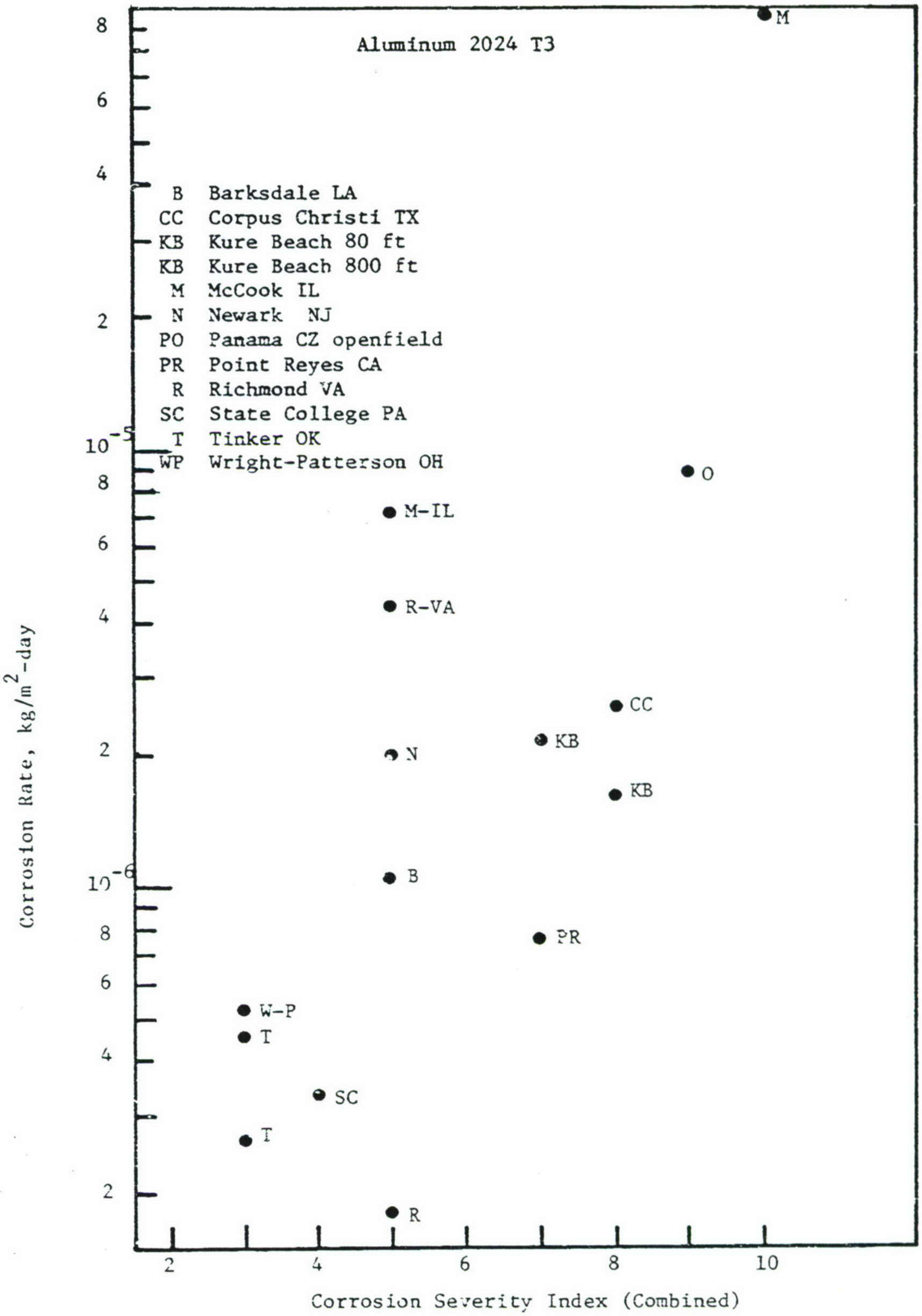

Figure 3. Corrosion rates of 2024 T3 Alclad Aluminum Alloy compared with environmental ratings.

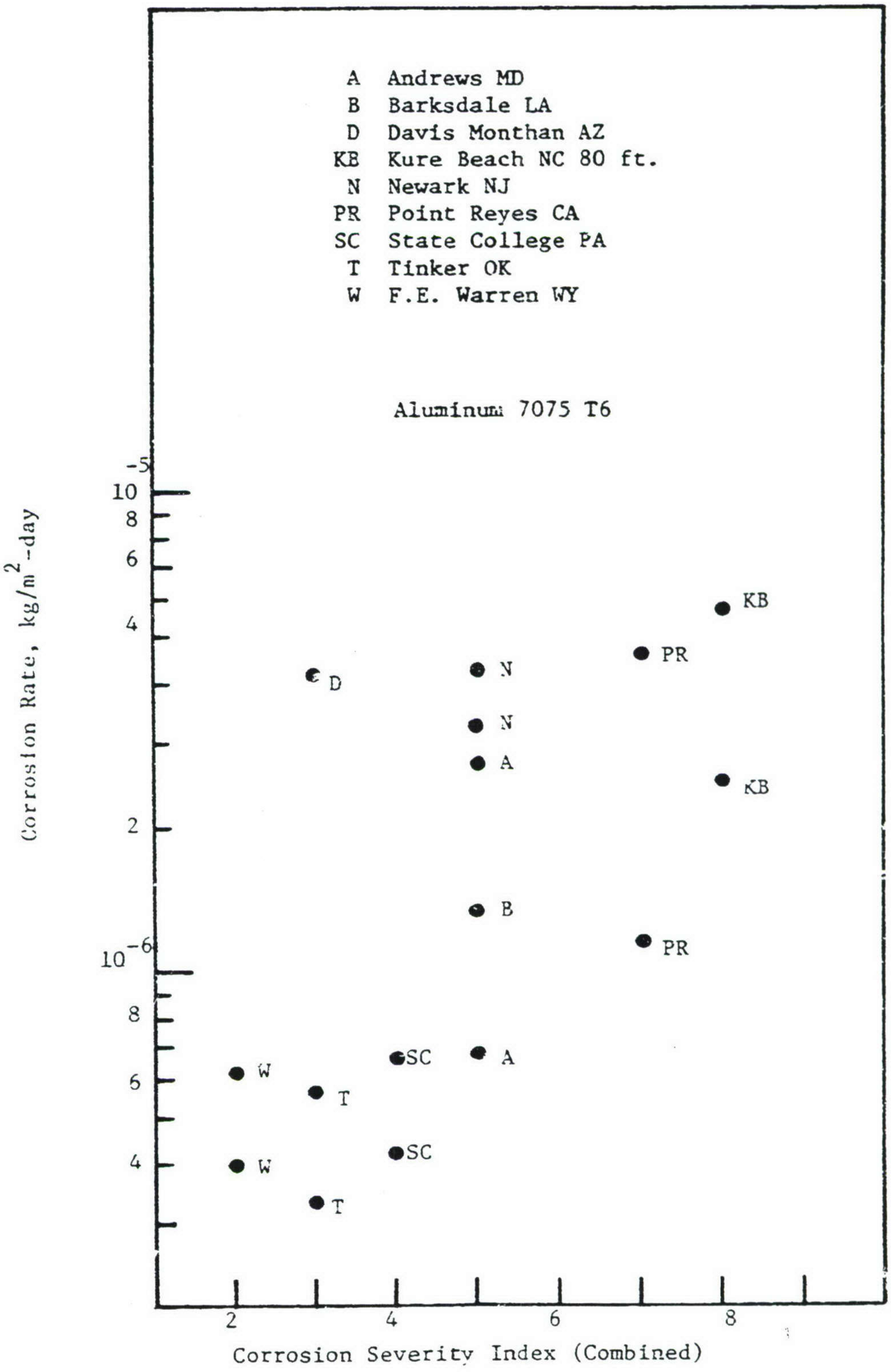

Figure 4. Corrosion Rates of 7075 T6 Aluminum Alloy compared with environmental ratings

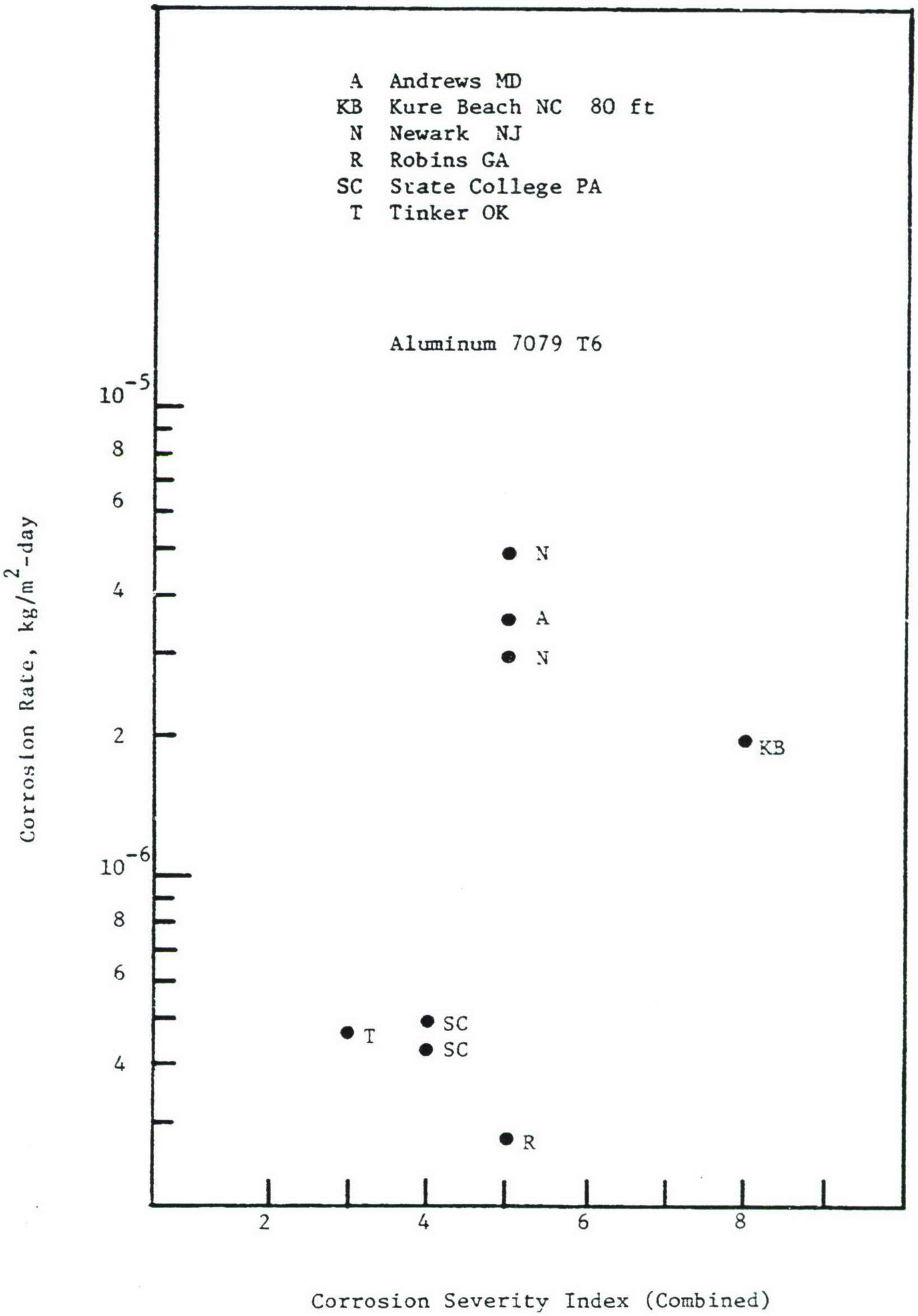

Figure 5. Corrosion rates of 7079 T6 aluminum alloy compared with environmental ratings.

In the case of 2024 T3 Alclad, Figure 3, nearly all the results are consistant with the exception of the ASTM McCook Il and Richmond VA values. The data for 7075 T6, Figure 4, are similar to those of 2024 T3. The PACER LIME 7079 T6 data consist of only four points, which are plotted in Figure 5 together with ASTM results. These all are consistent with the CDA environmental ratings.

Finally to compare the experimental results with the environmental ratings of the PACER LIME Interim Corrosion Severity Classifications, the data are shown in Figure 6. The correlation is less satisfying than that with the CDA results of Figure 2.

5. CONCLUSIONS

The experimental phase of PACER LIME was intended to yield adequate data for calibrating the Corrosion Factor Equation by measuring weight losses of panels exposed at several airbases. The results are less useful than had been expected for several reasons

(1) Although the metals tested were typical aircraft alloys, they were not especially suitable for measuring environmental corrosivity by weight-loss methods. The aluminum alloys are relatively resistant to general corrosion and weight losses were quite small and potential experimental errors large. Likewise the titanium alloy essentially did not corrode, yielding no data.

(2) Test sites which yielded data were quite similar and more-or-less moderate, whereas the mild and severe test sites were unproductive.

(3) Experimental methods were seriously flawed in two ways:

(a) Rubber-stopper rubbing to remove corrosion products before weighing is not reproducible from one technician to another, and moreover, is not effective in removing such material.

(b) Removal, cleaning, and weighing all panels at six-month intervals was an unfortunate choice which simultaneously lost information from the experiment, overburdened technicians, and multiplied the opportunity for error.

(4) This was, in fact, a large and complex program, with a very significant potential for expanding our knowledge of atmospheric corrosion. The resources committed to it, however,

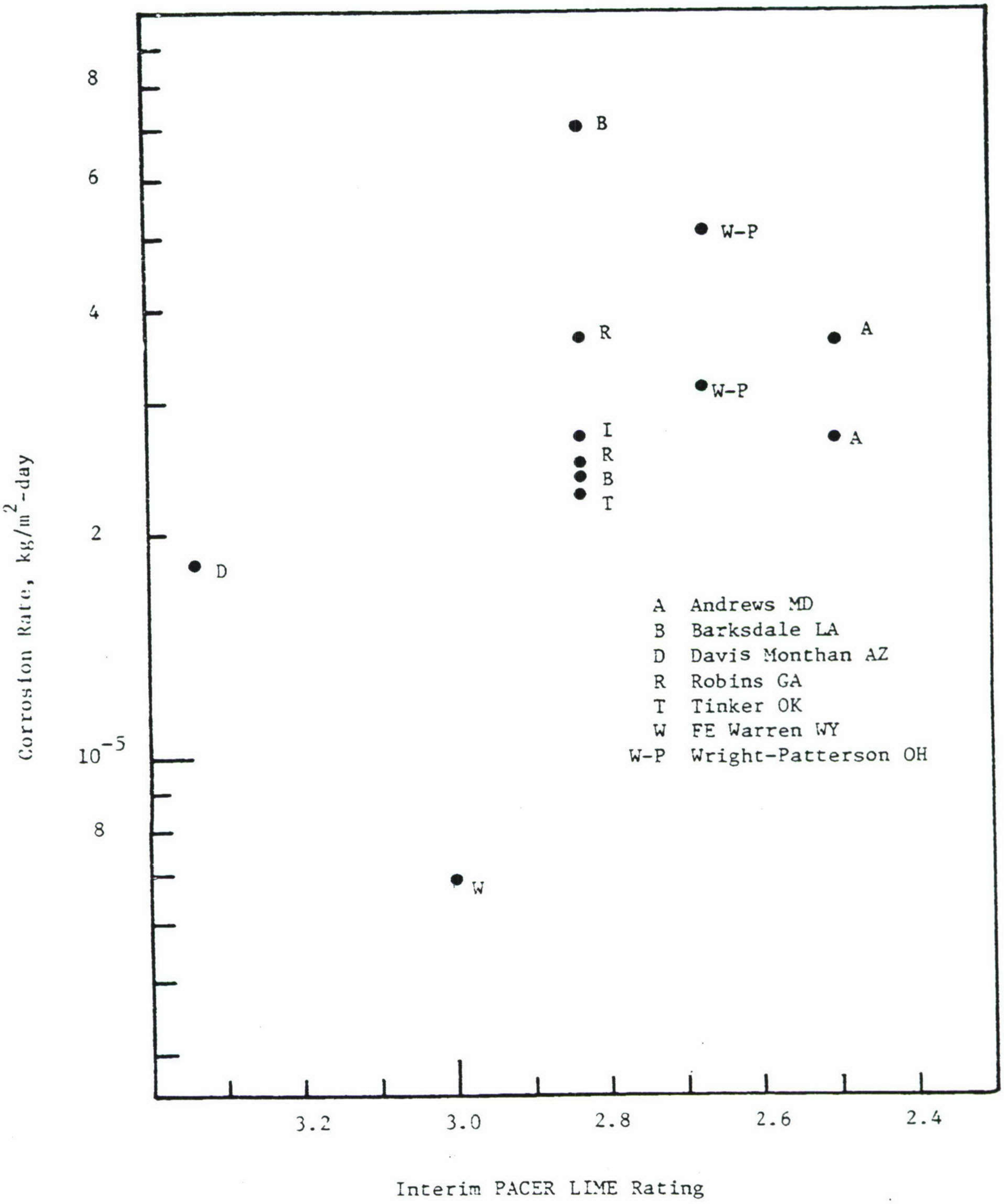

Figure 6. Corrosion rates of AZ31 B Magnesium Alloy Compared with PACER LIME Interim Corrosion Severity Classifications.

were inadequate for its scope.

(5) Although misfortune will befall any venture, PACER LIME was plagued with a measure larger than it deserved.

Considering these facts together with the scant data returned by the experiment, it is difficult to give serious weight to the apparent relative corrosivity of each test site. Despite all the flaws in the experiment, however, (1) the results are entirely consistent with those of other workers who have studied corrosion rates of the same alloys, (2) the results are in agreement with USAF maintenance experience as contained in AFM 66-1 records (cf. p. 63 Part I of this report), and (3) the results confirm relative environmental ratings from the Corrosion Damage Algorithm.

We conclude that the experimental phase of PACER LIME was successful in supporting a priori environmental corrosion severity ratings. Its success did not extend far enough, however, to provide a basis for a more accurate rating system.

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